Futurecasts from experts panels

Summary

The convening of both the scientific panel and the stakeholders panel provided the opportunity to gather opinions on how aquaculture feeds, aquaculture products and human nutrition will develop in the future. Participants in each panel were asked to predict the challenges and changes that aquaculture will face, and the developments that will affect both producers and consumers, over the next 5 and 25 years.

As noted before, at the end of the discussions, each panel member was assigned the following "homework" designed to provide a set of visions for the future of feeds for aquaculture:

> *The Future of Aquafeeds . . .*
>
> *This is a take home assignment–each participant should send in within two weeks following the meeting, what they see happening in the next 5 and 25 years in the area of feeds for aquaculture. This is an exercise in science fiction so please take your best guess and use your imagination but be honest in what you really see as the future of aquafeeds. Please keep each Scenario (5 years from now and 25 years from now) to under 2 pages in length. As much as possible make them applicable to your location and species. Let us know what the diets will be composed of, what the feed efficiency and growth rates will be and what breakthroughs occur to make your scenarios possible. Where will the limiting nutrients come from and what feedstuffs will dominate the industry in your country? What species will these diets be fed to? How much aquafeed is being produced worldwide? How are these diets sustainable in the long run? You are welcome to also put in natural disasters which might affect aquafeeds.*

All the submitted future casts are collected in this section following the summary. Participants in each panel varied widely in background and expertise and represented multiple viewpoints. Futurecasts represent the opinion and creativity of the authors, and should be considered works of fiction.

Aquaculture feedstuffs (proteins and oils)

Many contributors cited the scale of the biofuels industry as the factor most difficult to predict, and likely to have a major impact on feed composition. This industry will have a major effect on the prices of grains and all other related foods. Production of biofuels from grains will also generate tremendous quantities of co-products such as distiller dried grains with solubles (DDGS). This product is currently of low value to the aquafeeds industry because of the low nutrient density, poor processing characteristics and variable quality standards, but in the next 5 years the quality of the product from some manufacturers will improve. In the next 25 years enhanced extraction and processing of DDGS will result in several types of products ranging from traditional DDGS to highly concentrated and digestible products. These products will be competitively priced and will likely be a part of all aquafeeds At the same time, the use of whole ground grains will decrease dramatically as the value chain for each crop changes, and the oil, carbohydrate and protein parts of the seed all have value. Necessity forces more complete use of each crop.

The wild harvest and processing of fish for human consumption produces tremendous quantities of byproduct in the form of offal from processing plants. During the pollock and salmon fishing seasons in Alaska for example, huge quantities of this waste stream are available in a short time window. Development of technology and capacity to stabilize the raw material for future conversion to feed will make this underutilized resource accessible and make fishing and feed production more cost effective. The resulting stabilized material will be a high quality protein and oil source for aquaculture feeds. Use of these products is expected to increase over the next 5 years with development of both on-shore and floating processing plants. It is predicted by some that within the next 25 years there will be full recovery and utilization of both commercial and sport fishing waste. It is also expected that marine harvest of new species such as urchins, isopods, and amphipods for inclusion in animal feed production will begin. It is reasoned that a far smaller proportion of the existing populations would be needed for feed if the harvest of animal protein is focused at lower trophic levels than the current anchovy, sardine and menhaden fish meal fisheries and the environmental impact would be far less. The harvest of krill is, and may continue to be, very controversial.

Current research demonstrates the feasibility of using a wide variety of non-traditional ingredients in fish feeds. These ingredients share a common approach of recycling nutrients, or capturing waste streams from other processes. The capture fishery by-products described above are a good example and others on the horizon include; microalgae grown for feed using power plant CO_2 off-gas as way to capture carbon dioxide and possibly co-produce ethanol and/or biodiesel from the algae; bacterial biomass produced by cleaning food processing wastes; fungal fermentations of plant materials to remove fiber, concentrate protein and remove anti-nutrients; insect larvae grown on a mix of substrates such as food wastes, DDGS from ethanol production, and livestock manure. Some of these ingredients sound far fetched at this time, but by the year 2033 it will be important to utilize every available nutrient stream, so that each of these products may play an important role in aquafeeds.

Long chain unsaturated fatty acids are one key to the heart and brain healthful properties of fish, and this nutrient class is currently the most limited of all nutrients. Currently, there appear to be limited options for obtaining the needed levels of EFA's. Genetic modification was one possibility identified. However, the controversy surrounding genetically modified organisms (GMO) has resulted in the aquaculture industry avoiding association with these products in any way. This is not thought to change over the next 5 or even 25 years for the animals that are produced. Nevertheless it is expected that feed ingredients that are produced from genetically modified plants will play an increasing role in the food supply, especially with regards to long chain omega 3 fatty acids. The demand for these important nutrients is exceeding supplies today, and there are few wild sources that can be harvested. These essential fatty acids are not naturally produced by terrestrial plants. In the next 25 years, oilseeds such as soybeans and canola will be genetically modified to produced these essential fatty acids in order to meet the ever expanding needs of the growing population. These same approaches may be used to add other nutrients such as vitamins or taurine to the plants to increase their nutritional value for both animal feed and human consumption. Genetic modification, mutation or selection will also be used to remove the anti-nutrients found in plants that are detrimental to animals and humans alike.

Aquaculture animals

Changes in the cultured aquatic animal populations, to favor animals that can better utilize plant based nutrients and perhaps tolerate the anti nutrients, are anticipated too. Current estimates suggest that less than 20% of worldwide aquaculture production comes from genetically improved populations, and many species still rely on wild populations for breeders. Over the next 5 and 25 years the proportion of aquaculture production coming from domesticated, selectively improved populations will grow considerably.

Aquaculture nutrition information

While new and improved ingredients will be vitally important for the aquaculture industry in the future, expanding our knowledge of nutrient availability will be essential for realizing the full value of new ingredients. In addition, knowledge of the nutrient requirements for each species at different stages of life is essential for efficient use of feeds. For some of the major commercial species this information is currently being used, but over the next 5 years more information will be available and applied to commercial production. In 25 years, feed manufacturers will be able to match the nutrient requirements for all commercially produced species to the available nutrients in the feeds. Ingredient substitutions will be possible without reductions in fish performance.

Impacts on human nutrition

There is an increasing awareness from the public regarding the health benefits of eating fish. Consumption of the long chain omega 3 fatty acids found in coldwater fish has documented beneficial effects on health. Nevertheless, there is some sentiment that farmed fish have lower nutritional value than wild fish. It is thought that the wild fish have more long chain omega 3 fatty acids. The fact is that these fats come to the fish through the feed and high omega 3 fat levels can and are being achieved in aquacultured animals. A second misconception is that farmed fish may have higher exposure to environmental contaminants. The fact is that exposure depends strongly on their feed and their rearing environment. Diets of farmed fish are under increasing scrutiny and testing to assure the absence of contaminants.

The public is becoming increasingly motivated by the quality of food, and aquaculture products will continue to be improved over the next 5 and 25 years. It is expected that within the next 5 years, research on human nutrition will establish minimum, uniform recommendations on EFA's intake as it relates to human health.

In conclusion

One condition was common to all scenarios and future-casts; human population growth continues and the demand for more fish and seafood increases. The need for aquaculture research to develop sustainable sources of nutrients and develop farmed aquatic animal populations that can thrive on a variety of nutrient sources is vital.

Individual futurecasts

Futurecasts are in random order and are unedited. *Futurecasts are works of fiction and are limited to the imagination of the individual writers*. Futurecasts in no way represent any agency or groups official position. They were submitted by individuals who have an interest great enough in the topic to cause them to put in the effort to write them. The points we asked the authors to cover include the following:

- → Please keep each scenario (5 years from now and 25 years from now) to under 2 pages in length.
- → As much as possible, make thgem applicable to your location and species of interest.
- → Let us know what the diets will be composed of, what the feed efficiency and growth rates will be, and what breakthoughs occur to make your scenarios possible.
- → Where will the limiting nutients come from and what feedstuffs will dominate the industry in the US?
- → What species will these diets be feed to?
- → How much aquafeed is being produced world-wide?
- → How are these diets sustainable in the long run?

You are welcome to also put in natural disasters which might affect aquafeeds.

Jay Whelan
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What do we see happening in the next 5 years with aquaculture as it relates to human health?

The public will become increasingly concerned about their health. We have an aging population and neurodegenerative diseases are becoming more and more prevalent (real of perceived). Other health issues related to chronic diseases that have a relationship to nutrition will become an increasing concern. How can diet maintain health and how can diet treat existing conditions. Diet has an advantage over targeted therapeutic agents because of minimal side effects. Long chain omega-3 polyunsaturated fatty acids (LC n-3 PUFA) posses multiple action in maintaining health and treating disease. Intake is inversely associated with neurodegenerative diseases (dementia, Alzheimer's), coronary heart disease, sudden death, cancers, inflammation, etc. As we age, the risk of developing these chronic diseases will increase and the desire for non-invasive nutritional treatments will also increase. Critical to the aquaculture industry is their ability to address the major concerns of the public. The biggest is providing a safe product with consistent quality control. To do this standardization within the industry is critical.

Currently, fish derived from aquaculture is perceived to be inferior to wild fish. There are concerns about contaminants (pesticide runoff, etc) and about nutritional quality. The public has the perception that wild fish have higher levels of LC n-3 PUFA and may have lower levels of methyl mercury, dioxin, PCBs etc. The industry has to convince the public that the safest fish is derived from aquaculture and its nutritional and sensory qualities rival that of ferel fish. The human researchers will be doing their part in establishing dose and response data needed to make informed recommendations. I suspect, in the next 5 years, their will be a drive to establish minimum, uniform, recommendations on n-3 PUFA intake as it relates to human health.

The demand for fish will increase if the concerns of the public are satisfied. I will predict that industry and governmental agencies will try to tighten quality control aspects. They will invest more money into research to establish these guidelines. The dietary requirements of different fish species need to be established through research that is published in peer-reviewed scientific journals.

The use of GMO feeds for fish will be a big issue and will need to be addressed through scientific investigation to minimize public concern. Genetic manipulation of plants that are used for fish feed will parallel the need for alternative food sources (i.e., plant meal and plant oils versus fish meal and fish oils). The technology exists.

What do we see happening in the next 25 years with aquaculture as it relates to human health?

Unless fish becomes a huge health concern, I predict that the need and use of fish products will increase over the next 25 years and this growth should be sustainable. The concerns over the use of biotechnical feeds will eventually subside due to market pressures and research that clearly establishes that the use of these types of feed have no human health concerns (if in fact that ends up being the case). Even now, the government's report about the health effects of LC n-3 PUFA asserts that the benefit of consuming fish out weigh the risks. Now, whether the global supplies can keep up with the public's demand is an issue that needs to be addressed by the industry. From a human health perspective, the consumption of fish and fish oils have shown and will continue to show health advantages over the use of other meats in the diet.

What are the long term solutions to existing barriers?

Research is the key. Research proper nutrition for fish and establish a database outlining these standards with proper testing to confirm the recommendations. Research the health effects in humans, including establishing the potential health benefits of "all" the nutrients in fish and fish oils (those nutrients in addition to LC n-3 PUFA). Genetically modify plants so they are adequate substitutes for fish meal and fish oil by enhancing required nutrients and minimizing anti-nutrients.

Craig Sheppard, University of Georgia Entomology
Gary Burtle, University of Georgia Animal and Dairy Science
Larry Newton, University of Georgia Animal and Dairy Science

Available studies indicate that a complete or partial replacement of fish meal and fish oil with black soldier fly (*Hermetia illucens* L.) prepupae protein and fat will occur rapidly, in the face of decreasing fish meal supplies. This will be based on additional research on all aspects of production, processing and utilization of this novel feed.

Feed efficiency and growth

A replicated study indicated that complete replacement of fish meal in channel catfish diets is possible with no decrease in growth or FCR. In rainbow trout a 25 percent replacement of fish meal with prepupae meal gave similar growth. However, 50 percent replacement resulted in a significant reduction of growth, indicating a sensitivity to soldier fly prepupae meal at high rates of dietary inclusion. Both of these studies used whole milled prepupae. Separation of the cuticle (contains chitin) from the protein and fat of the prepupae will produce a superior feedstuff. A preliminary analysis indicated that cuticle weight is about 24 percent of the whole prepupae on a dry matter basis. Removal of this chitinous material will improve performance and increase the percent of fish meal that can be replaced in diets for sensitive aquatic animals as well as pay for the cost of removal by sales of the valuable chitin.

Production breakthrough

Development of large scale production of black soldier fly prepupae will require scaling up and refinement of already proven systems. After large quantities of prepupae are available, byproducts from the production of soldier fly prepupae meal will include chitin, fat, protein concentrates and fine chemicals. Commercial equipment is, or will be available to separate these product streams and markets exist for the byproducts. By 2013, large scale production of soldier fly prepupae will be located in close proximity to the major aquaculture producing areas in the nation. The ability of soldier flies to use a variety of substrates for growth, while producing a consistent product, will makes them the preferred protein production alternative.

Species fed, designer and organic feed

Although plant protein has been shown to provide good growth for aquaculture species, including tilapias and catfish, soldier fly prepupae meal can replace fish meal in high efficiency diets and in the diets of carnivores. Dietary inclusion of up to 30 percent can be achieved for most fish and crustacean species. Development of a soldier fly prepupae meal after the chitin or skin has been removed will allow a higher level of dietary inclusion for sensitive aquaculture species, like rainbow trout. By 2033, all aquaculture diets will have soldier fly prepupae inclusions levels between 5 and 75 percent. Larval fish and crustacean diets will also be greatly impacted by the development of soldier fly prepupae meal due to their higher requirement for animal protein

"Designer" and organic feeds

Supplementation of substrates for production of "designer" prepupae is highly desirable to increase the amount of omega-3 fatty acids and adapt the final composition to specific needs of aquaculture species. Diets for brood stock, especially shrimp and marine finfish, will benefit from designer soldier fly prepupae containing high oil, high omega-3 concentrations. Designer soldier fly prepupae will not be GMO, and may use substrates of "organic" origin to supply the food stock to produce "organic" and enriched feed-grade protein concentrate. The unique and controlled nature of soldier fly prepupae production allows for manipulation of the final nutrient composition of the product. This aspect provides an advantage over many protein products with variable source and manufacturing characteristics that change product composition, including fish meal, poultry by-product meal, and meat-and-bone meal.

Feed needed

Aquaculture feeds that include commercial sources of fish meal, estimated on the basis of shrimp, salmonid, catfish and tilapia production, are about seven million tons worldwide. Base on the SOFIA projections for growth in the industry, 8.7 million tons will be needed in 2013 and 13.5 million tons in 2033. The amount of soldier fly prepupae meal needed will depend on the dietary inclusion rate and the rate of penetration of this new product into the feed protein market. The projected 10 percent average dietary inclusion rate and 50 percent penetration rate, 675,000 tons of soldier fly prepupae meal and protein concentrate will be needed by 2033.

Production Possible Prepupae production from just two previously researched "waste" streams from the U.S. alone can meet the projected needs. Also, many other feedstock streams and those outside the U.S. can be used. Production from manure of confined swine in the U.S. alone would be 1.8 million tons of prepupae. Another more easily accessed feedstock is U.S. brewer grains, which would produce about 500,000 tons of prepupae annually.

Insect utilization, nutrients, antimicrobial

Many populations of wild animals, especially fish, birds, bats, and others, depend upon consumption of insects for a significant part of their nutrition. Most scientific effort devoted to insects has been aimed at destroying pest species, rather than using beneficial species. This vast production potential of insects will finally be used in support of the human food chain by developing the commercial production of *Her-*

metia to feed our farmed fish. The composition of whole unseperated *Hermetia* prepupae meal is about 42 percent protein, 35 percent oil, 5 percent calcium, 1.5 percent phosphorus, 3.4 percent lysine, and 1 percent methionine/cystine. Interestingly, *Hermetia* meal oils contain about 54 percent lauric acid which has been shown to be active against oil coated viruses, including HIV virus, measles virus, clostridium, and many pathogenic protozoa. The high quality and unique characteristics of *Hermetia* meal will have many uses in the aquaculture and other animal industries.

Sustainability

Black soldier fly (*Hermetia*) upgrade lower value materials into a source of animal protein (and oil) which has a much higher value, especially as an ingredient in diets for fish. When these lower value resources (such as waste food, by-products of the alcoholic beverage or ethanol industry, or animal manure) are consumed by Hermetia, the process also serves as a treatment that reduces the volume and nutrient content of the starting material. This is especially important, for increasing sustainability, in the case of animal manures (which are often produced in excess of local demand) and materials that would otherwise end up in landfills. *Hermetia* production will be sustainable in that it uses underutilized materials and, in turn, it increases the sustainability of the endeavors producing these materials.

The demands of the U.S. economic system which favors large scale production, established supply chains, and centralized distribution; puts distributed production (which is often more sustainable and usually the place of new commodities), at a distinct disadvantage. Systems of distributed production usually develop to supply a specialty market. The aquaculture feed industry will be enough of a specialty market to support the development of *Hermetia* culture into commodity status within 5–10 years. Other animal industries, that use fish meal, will also benefit from the availability of *Hermetia* meal. With sufficient penetration of the feed protein market by *Hermetia* meal, the demand for wild capture fish meal will move more into line with sustainable harvest.

Jeff Silverstein
USDA/Agricultural Research Service

In 2008

Protein-heavy reliance on fish meal, supply is limited. Protein alternatives exist, research ongoing to develop alternatives, examine impacts on product quality.

Oils-heavy reliance on fish oils, supply is severely limited. Oil alternatives exist for some of the demand, but HUFA (esp. EPA/DHA) alternatives not certain. Some precursors available from transgenic plants (stearidonic acid?)

Feeding-phase feeding and definition of requirements for different phases, endpoints is in early stages (at best).

Genetic improvement of fish, very early for all but Atlantic salmon (24–28 months to harvest @ 4kg) and maybe rainbow trout (9 months to harvest @500g). Even the salmonids have great potential for improvements in growth, possibly in broadening the materials that can be used/tolerated in feeds. Genetically improved populations supply ~15 percent of aquaculture production.

In 2013

Protein-Variety of protein sources in use and phase feeding important to minimize problems with specific compounds

Oils-the critical limitation, focus on phase feeding to meet requirement pre-harvest, and meet consumer need at harvest. Discussions about use of transgenic plants to deliver the HUFAs, transgenic animals to make their own HUFAs.

Genetic improvement progressed for salmonids. Harvest salmon at 20–24 months, rainbow trout at 8 months. Genetically improved populations supply 30 percent of aquaculture production.

In 2033

Protein-dietary protein will be supplied from a variety of ingredients, aquaculture will still be a big user of fish meal, but a smaller and smaller fraction per kilo of diet (just more kilos of diet). Delivery, absorption and availability of amino acids will be the major issue-having all the a.a.'s available at the same/right timing. All requirements for amino acids for the major species will be known and met for up to 5 separate growth intervals.

'Special factors' in fish meal will be identified.

Oils–New sources of HUFAs available from algae, possibly transgenic sources of HUFAs. The requirements for various species of FA will be defined (e.g. the roles of EPA/DHA). Phase feeding will be routine.

Krill will be harvested sustainably and provide one alternative for marine oils and proteins.

Genetic improvement-fish will supply a much bigger share of proteins in the world food supply. Genetically improved populations will supply the majority of aquatic foods. Growth rates will be the prime improvement, followed by disease resistance. Salmon will be harvested within 6 months of seawater transfer. Trout will be harvested 5 months from hatch. Larval feeds will be optimized, selection on artemia and copepods for smaller sizes to feed first feeding juveniles.

Rick Barrows
USDA–Agricultural Research Service

Past and Present

Research on replacements for fish meal in aquaculture diets has been conducted since the early 1970's. At that time fish meal and fish oil was relatively cheap and supplies were large and high quality. The primary factor driving the early research on alternative protein sources was simply to reduce feeds costs. In the late 1990's research intensified on a global scale to find replacements for fish meal. Many factors were driving this research effort including increased demand with static supplies, a more restrictive regulatory environment, and detection of contaminants in fish oil and meals. Recent studies have demonstrated that fish meal can be totally removed from the diet of some carnivorous species without a reduction in fish performance. This research demonstrates that elimination of fish meal from carnivorous fish diets is feasible, but other obstacles remain for other species.

The problem facing the aquaculture feeds industry today is not just finding better ingredients. The situation is more complex with several major factors limiting progress in removal of fish meal from aquaculture feeds. First, relative to terrestrial animal species little is known of the complete nutrient requirements for the variety of aquaculture species. Some amino acid requirements have been determined for several species using purified diets, but this information does not seem to be effective with practical feeds fed to fast growing strains of fish. Second, specific nutrients not normally considered when formulating fish meal based diets must be accounted for in the diet. Some of these nutrients include, taurine, hydroxyl-proline, macro-minerals, and insositol and more are currently being identified. Third, the number of ingredients available with the proper nutrient composition (i.e. protein greater than 55-60 percent) is very limiting. Alternative sources of essential fatty acids (other than fish oil), both for fish metabolism and human health, are currently not available. Fourth, the industry needs to move away from formula based diets and into nutrient based diets, but a better understanding of the availability of nutrients from the alternate ingredients, and the requirements of the fish, is critically needed for this progress to happen.

Five years from now

More of the essential nutrients in fish meal have been identified and are supplemented or balanced allowing increased use of alternative ingredients. The role of plant products in aquafeeds will be strongly influenced of the expansion of the bio-fuels industry. As ethanol production consumes more grains, methods to improve the quality of DDGS, resulting in lower fiber products with increased amino acid availability will be developed. A whole series of protein ingredients will be developed on the basis of sustainability and nutrient recycling, and will be evaluated with many species, but not yet comprising a major portion of the aquafeed market. These include micro-algae's grown using power plant off-gas as way to capture carbon and possibly produce ethanol and/or bio-diesel at the same time. Fishery processing wastes will play an increasing role as traditional capture fishery meal replacement, but primarily in starter feeds. Bacterial cultures that are used to clean up food processing waste streams will then be used in aquafeeds. Fungal fermentations will be used to consume anti-nutrients from plant products and produce proteins. Insect larvae grown on a variety of co-products including DDGS from ethanol production, food wastes, and livestock manure will be used in some feeds. Phase feeding fish oil (used only during the last phase of production) will be common practice to conserve the limited supplies. At the same time more research on human nutrition will help in determining the target levels for essential fatty acids in fish fillets.

Twenty five years from now

All species of fish produced in large scale will be using nutrient based formulations to allow for fluid transitions of ingredients in the diet as ingredient cost and availabilities change. Nutrient requirements will be known for the major life stages for many species. Out of necessity, and due to rigorous testing, the public has accepted the production of genetically modified oilseed crops (soybeans, canola, flax) that contain the omega 3 fatty acids previously found only in fish oil. If these products are affordable they will be fed throughout the life cycle of fish, or perhaps just used as in finishing diets as fish oil was used in the past. The majority of fish oil will be used directly as human food. Modified ingredients tailored for specific aquaculture feeds will be fully developed and utilized in aquafeeds. Nutrient recycling is not only important, but the only economically way to continue production. Modification of plant products through processing or genetically will remove the problem of anti-nutrients. Enhanced strains of fish will improve production efficiencies and remove any problems with palatability of alternative ingredients. In summary, better fish, more alternative ingredients and improved feeds will result in a strong industry providing a healthful product to the consumer.

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Assumptions

Worldwide aquaculture production has grown at 10 percent per year and has tripled to approximately 100 million metric tons per year. Assuming an overall feed conversion of 1.5 this means 150 million metric tons of aquafeeds per year.

Fish meal and oil production are static at 6 million metric tons and 700 thousand metric tons respectively. Assuming 100 percent of these products were used in aquafeeds that means 4 percent fish meal and 0.47% fish oil in the average aquafeed formulation.

We will need approximately 10 million metric tons of high quality protein and 2 million metric tons of vegetable oil containing high levels of highly unsaturated fatty acids to replace marine products in aquafeeds.

Protein

Anti-nutritional factors (ANFs) present in plant proteins mean that we will have to develop: 1) biotechnology produced crops with lower levels of ANFs than current crops and 2) methods of processing crops to reduce levels of ANFs.

The palatability of plant proteins is lower than that of marine products. This will require: 1) the development of palatability enhancers and 2) strains of fish that accept high dietary levels of plant proteins.

Complex diets formulated with many plant proteins support higher growth performance than simple diets. We will require a moderate number (more than 6) of high protein ingredients for tomorrow's aquafeeds.

Increase the amount of marine products available for aquaculture by harvesting products at a lower trophic level.

Oil

Fish oil contains high levels of highly unsaturated fatty acids (HUFAs). To maintain the nutritional quality of fish products, alternatives to fish oil must also contain HUFAs. This will require biotechnology produced oilseed crops that produce HUFAs.

Products we will be using in 2020

- Aquaculture grade soybean protein concentrate (Low ANF varieties processed to increase protein content)

- Corn gluten meal (an old standard)
- Canola protein concentrate (60 percent crude protein with low levels of ANFs)
- Pea protein concentrate (55 percent crude protein with low levels of ANFs)
- Distillers dried grains and solubles protein concentrate (relatively cheap and palatable)
- Aquaculture grade marine meal (harvested from low trophic level marine organisms)
- Fish meal (used at low levels to improve palatability and growth performance)
- High (HUFA) soybean and canola oil
- Poultry meal
- Fish oil (used in final finishing diets for flavor enhancement)
- Palatability enhancer (plant based protein source with attractant/palatability enhancer properties)

Areas of Required Research

Plant science-development of crops specifically for aquaculture diets.
Soybean –proteins and oils
Canola-proteins and oils

Aquaculture nutrition
Develop a better understanding of the effect of plant ANFs on fish metabolism, physiology and intestinal microflora.
Use of new products in aquaculture diets.

Fish nutrigenetics
Develop improved strains of fish that better tolerate plant proteins and oils in diets.

Human nutrition
Increased knowledge of the benefits of fish in human diets is essential to developing consumer buy-in.

Marketing
Improve the acceptance of farmed fish by the consumer.
Both nutritional and environmental aspects of aquaculture products must be promoted.

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National Research Institute of Aquaculture (NRIA)
Feed Research Group, Aquaculture Systems Division

Background and present situation

Japan used to be the leading fish meal manufacturer in the world. For example, in 1980s there were constant 3-4 million mt or more of sardine (*Sardinops melanostictus*) fisheries production from the surrounding seas of Japan. At that time this huge catch of sardine substantially supported the large production of developing sector of the aquaculture of high commercial value fish like yellowtail (*Seriola quinqueradiata*) and red sea bream (*Pagrus major*). However after 1990s Japanese sardine production drastically decreased mainly due to the influence of natural regime shift occurred in oceanic environment with long-term intervals. To compensate this collapse of sardine production Japan started to import large amount of fish meal products from Peru, Chile and many other countries, and its total amount reaches 400–500 thousands mt nowadays. Approximately 50 percent of the imported fish meals are used as a feed ingredient for cultured fish and eventually 400–500 thousands mt of formula fish feeds is produced for finfish culture in Japan. However the recent soaring of fish meal price due to the increase in demand and international scrabble for fish meal products make the situation difficult from economical reason. In addition to that due to the influence of global climate change, the productions of pelagic feed material fish like sardine and anchovy are not always stable and predictable anymore. On the other hand, world aquaculture has become a dynamically developing sector of the food industry in recent years. With stagnating yields from capture fisheries and increasing demand for aquatic products, expectations for aquaculture to increase its contribution to the world's production of aquatic foods are very high, and there is also hope that aquaculture will continue to strengthen its role in contributing to support human health and sustainable food supply.

Under these state of affairs, for the advancement of aquaculture sector in Japan, the National Research Institute of Aquaculture has been participated an exceptionally imperative role as a governmental research institute hitherto. Its recent research activities on feed ingredients can be categorized as follows: 1) Efficient utilization of plant-derived feed ingredients like soybean meal, 2) Efficient utilization of plant oil and carbohydrate as feed ingredients for marine finfish, 3) Necessity of taurine as an important nutrient for marine finfish, 4) Improvement of fish feeds without fish meal using bile salts and taurocholic acid, 5) Efficient utilization of single-cell materials produced from seaweed biomass by enzymatic means for aquafeeds. The outputs from these research activities made a great contribution for the development and improvement of aquafeeds used for finfish culture not only in Japan but also all over the world. However we are now required to propose novel and innovative ideas to give breakthrough this difficult situation surrounding aquafeeds mentioned above. As the head of feed research group of NRIA I imagine and forecast my personal opinion on the future of aquaculture and aquafeeds in Japan in 5 and 25 years time period from now. To avoid confusion the subject of the following prospects restrict only on feeding cultures of finfish and aquafeeds used for them.

Five years later from now

Net-cage culture of highly-economic finfish will be amazingly popularized in Japan. The main target species are marine species like blue-fin tuna (*Thunnus thynnus*), amberjack (*Seriola dumerili*), yellow tail (*Seriola quinqueradiata*), red sea bream (*Pagrus major*), tiger puffer (*Takifugu rubripes*), Japanese flounder (*Paralichthys olivaceus*), groupers (*Epinephelus* spp.), etc. moderately a huge quantity of flesh harvest will be exported to the new market formed in main terrain China and other Asian countries. The consumption of seafood will be increased among the prosperity living coastal area in China, and eating puffer fish is not illegal any more. For some species like red sea bream and Japanese flounder commercial hard pellet formula diets are given by using computer-controlled automatic feeders equipped with solar panel. Sophisticated demand-feeding apparatuses are developed and commonly utilized to minimize the loss of feed and unexpected load of N and P to the water environment. Some parts of fish oil can be successfully replaced by DHA extracted from cultured protist biomass like marine net slime molds *Labyrinthula*. More than 50% of dietary protein is plant-derived protein like DDGS that are completely proved to be safe as human food and for environment.

For some important cultured species like blue-fin tuna, amberjack, yellowtail and tiger puffer, so-called Oregon-type moist pellet are still used for growing out to commercial size. This modified Oregon-type moist pellet are comprised of fish process by-products, single-cell materials made from seaweeds and local fish meal made from Pacific saury (*Cololabis saira*) and anchovy (*Engraulis japonica*). Harvested fish are processed into fillet and/or block forms near aquaculture sites and ship to the market or other area to reduce the transportation cost. Fish trimmings and left-over wastes can be reused as one of the main feed ingredients without freezing storage; i.e. lighter eco-mileage and eco-friendly feedstuff. Near the net cages for fish culture aquafarmers are encourage to culture edible seaweeds like laver (*Porphyra* spp.), wakame (*Undaria pinnatifida*), and sea tangle (*Laminaria japonica*) as water quality conditioners; a kind of new integrated fish culture. Good seaweeds products are supplied for human consumption and pharmaceutical use, and the other low grade products will be used as feed ingredients after some single-cell processing using enzymatic means. The import of high price fish meal from overseas might be gradually reduced due to the exploitations of new fish meal materials that can be harvested near the seas of Japan. In general, aquaculture would be progressively a growing sector of fisheries and its products are recognized as good commodities to earn money not only in Japan but also all over the world for a while.

Twenty five years later from now

From world wide point of view, the main role of aquaculture will be completely altered due to the explosive increase of world's population and the unexpected change of global climate in future. According to the many statistical data the world's population, on its current growth curve, is expected to reach nearly 9 billion by the year 2050. This number is certainly beyond the limit that the earth can support its food for world people to live on. In 2033, 25 years later from now, the situation surrounding us will be getting closer to this critical phase. Under this difficult condition the importance of aquaculture would become greater and greater to produce good food resource for humans. People cannot depend on small pelagic fish as feed ingredients for culturing fish anymore. Most of the fish caught in the sea are used as excellent foods for human being; even they are very small in size. Almost all the feed stuff for aquaculture will come from organic by-products and wastes. By utilizing DDGS obtained after biofuel processing as one of the main protein source omnivorous and herbivorous low-trophic level fish which require less dietary protein will be widely cultured and supplied to the consumers as cheap and healthy foods.

For culturing high commercial value fish, most of them are highly carnivorous, fish wastes and meals from terrestrial animal wastes are used as main feed ingredients. For CO_2 fixation genetically modified high-performance microalgae are widely cultured in ponds near factories and power plants. By feeding these microalgae huge amount of microscopic plankton (*Brachionus rotifers*) can be produced. Also as rotifers are utilized for sewage treatment people have continuous supply of this nutritious zooplankton. After extracted oil for bio-diesel, rotifer wastes are utilized as alternative protein source for feeds for fish as well. Of course this rotifer is a GM strain which produce enough amounts of HUFAs including DHA and EPA.

Genetic modification technology and GMO will be played a very important role when we use crop meals and DDGS as a main feed ingredient by modifying its nutritional profile and improve its nutritional faults and demerits. Nevertheless we should always keep it in mind that it is prerequisite to be proved and insure safety as human foods and for environment from any view points.

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5 years from now

In Japan aquaculture industry of 5 years later, the economic and environmental problems from fish meal probably has become more serious, and utilization of the alternative protein sources will be promoted. Plant proteins such as defatted soybean meal and corn gluten meal are practical alternative protein source. As reported at the meeting of the other day, taurine is very important for marine fish species, which are main aquaculture species in Japan. However, the plant protein sources are not containing taurine. There are 2 types of nature and synthesis in the taurine. Since the price of natural taurine is high, the natural taurine cannot use as a feed additive. Although the synthetic taurine is very reasonable price, the use of synthetic taurine as a feed additive has not yet authorized by the Japanese government. Therefore 5 years from now, the Japanese researchers will be made a several attempts to obtain the judicial applications of synthetic taurine use as a feed additive.

Presently, in Japan the use of meat and bone meal from bovine as a feed stuff is under ban of the law for the influence of bovine spongiform encephalopathu (BSE). Furthermore, for the influence of avian influenza the use of chicken meal as a feed stuff is sidestepping from the consumer. Therefore, the appearance of novel animal protein source is expected. Soon, the use of meat and born meal from pig as a feed stuff will be authorized by the Japanese government. Therefore 5 years from now, the Japanese researchers together with feed companies probably examine the practicality of meat and born meal from pig.

25 years from now

It is very difficult to expect the future of 25 years later. When present condition is considered, fish meal and fish oil probably could not use as feed stuffs in 2033. As reported at the meeting of the other day, the gene recombined DHA and EPA containing soybean and phytate free soybean will be authorized by the United States. Furthermore, the gene recombination will probably make the optimal soybean for aquafeeds (e.g., lysine, methionine and taurine rich soybean, free from antinutritional factors (i.e., lectines, antigenic and estrogenic flavons, oligosaccharides, and else) free soybean. Presently, Japanese many people have negative image in the gene recombined foods. However if United States promotes the utilization of gene recombined soybean, Japan cannot avoid using that soybean, so Japan has imported much soybean from United States. Therefore, in order to improve the negative image for the gene recombined soybean of the Japanese people, the Japanese researchers will examine the safety of gene recombined plant source.

Roberto Marchesini

As the note you gave us said: “take your best guess and use your imagination”, I took some liberty to write down some ideas I have and imagined what I would like or what I might think will happen to aquaculture and aquaculture feeds. I hope that you like what you read and also that this will help you to do your work.

I was a foreign participant at the meeting, I live and work in El Salvador, Central America as an aquaculture consultant and I work mainly with tilapia, freshwater and marine shrimp in semi-intensive systems. This exercise about aquaculture and aquacultured feeds problems has taught me a new tool that I might use to propose the development of aquaculture policies in my country.

I would like to thank you and the organizers of the event for letting me attend and express some of my ideas. Please send them my regards and congratulations.

Sincerely yours,
MSc VMD Roberto Marchesini

This is the year 2013 in USA

America is working harder on *Tilapia*, marine and fresh water shrimp culture. The diets formulations on those animals have been changing and by now those aquatic animals nutritional requirements are known. Essential fatty acids oils of fats and essential aminoacids of the proteins minimum percentages of the diets on those animals on their different stages of their lives have been researched and revealed by the National Research Council, the most important agricultural oriented universities or other scientists. Those discoveries have been accomplished thanks to the available grants given by the Sea Grant and some other governmental entities to the interested scientific community in the following of this line of investigation.

Aquaculture of *Tilapia*, fresh and marine shrimp is now more intensive due to the public demand of those products. Due to the specificity of the nutrient requirements on the diets there are needs of cheap sources of fat and proteins (essential fatty acids and aminoacids, that is) and so there is an emerging industry of guts and leftovers recycling of the main fresh and seawater fishing and aquaculture industries (salmon, Alaskan crab, trout and some others).

Feed conversions and growth rate still remains almost as 5 years before without much of a change, but aqua-farmers income is somehow increased not because of the reductions of the cost of the main feed ingredients (fats and proteins) but because of the appropriate nutrition of the broodstocks. Price reduction of feeds is not quite a reality yet because of the increase in prices of the other ingredients of the feed, for instance corn, sorghum, gluten and wheat meals have sky rocketed because the Biofuels policies in the US and worldwide.

Those diets will work for now but aquaculture has kept on growing at a steady pace for the last decades that there might be a shortage over the next years on the quality and quantity of the feeds ingredients.

More to come....

This is the year 2023

Industrial intensive and super-intensive aquaculture is the way America has chosen to compete against cheap, polluted, non-environmental friendly seafood raised in China and other eastern countries.

Freshwater and marine shrimp and Tilapia have been under a protocol of genetic improvement for a few years now. Many of the nutrients probed for adequate human health and nutrition are fulfilled by aquacultured seafood. Essential aminoacids and fatty acids needed in children, mature and elderly people are commonly found on seafood, because those aquatic animals have acquired capability of retain certain nutrients of feed.

By now feeds in many places are a special mixture of certain strains of intensive cultured bacteria, microalgae and yeast. Following the lead of Norwegian scientists, US industries developed bacterial cultures and genetically modified them to obtain all components of the different nutrients needed in aquaculture feeds. Those microorganisms are nurtured on LPG (like the Norwegian strains) or a mixture of sunlight and special nutrients in the form of fertilizers.

Microalgae, bacteria and yeasts now easily produce fatty acid oils and aminoacids in intensive facilities, those are required by aquaculture feed industries in the form of semi-liquid biomass and are processed to produce dry protein meals, fluid essential oils and unspecific growth and immunologycal stimulant factors. Nutritional requirements of aquacultured broodstocks are known since many years ago and those environmental friendly cultures are supplying what is needed.

By now feed efficiency is almost reaching 1:1 levels and growth cycles have diminished around 15 percent compared to 25 years ago because of the high digestibility of feeds and the unique improvements in genetic lines of broodstock.

Apparently the major limiting feed ingredients are corn, wheat and sorghum meals and similar due to environmental factors originated by global warming that has affected crops with droughts, hurricanes and related events.

Anonymous One

In looking forward to 2013 and 2033, it is apparent that the continued growth of aquaculture will demand more and more sources of natural proteins. This will be based on the international interests in "lifestyles of health and sustainability" (LOHAS), the interest in natural and organic products, and the awareness of many unknown health factors with "genetically modified" foods and from contaminates through chemical enhanced growth and processing. This will help spur a market for natural foods that can be made from unused biomass available in fish and invertebrates, including marine and land based organisms.

From Alaska, the future sources of aquaculture food materials exist in three areas: recovery of biomass from fish processed for human consumption, including salmon, pollock, cod, halibut, other flatfish, and rockfish; new reduction fisheries for arrowtooth flounder; and harvest of aggressive marine invertebrates, including urchins, isopods and amphipods for reduction.

While large biomasses exists in Bering Sea clams, arctic krill and other euphausids, they are important food sources with ecological links through the food chain to marine mammals, also key elements to the Alaska's marine ecosystems.

In this context, I offer the following perspectives on the year 2013 and 2033:

In 2013, market forces, business interests, and regulatory schemes will move towards optimized use of the existing seafood processing biomass. This will build upon the present fish meal and oil recovery capacity in the shoreside plants and offshore catcher/processor vessels. Existing plants will be increased in capacity through a stabilized fish processing waste process, allowing peak periods to be carried through times of limited returns. New floating plants will be located in Prince William Sound and Bristol Bay to allow handling of the processing volumes in the surrounding area. The support tugs that brought the floating plants to the area will work in transporting bladders of stabilized waste from various fishing communities to the floating plants. Meals and oils will be stored in the nearest community awaiting shipment to a major cargo port upon completion of season. New shoreside plants will be planned in the Prince William Sound, Bristol Bay, and the upper areas of Southeast Alaska with particular interest in salmon, based on the business viability of the floating plants. As developed shoreside, floating plants will move to areas other areas as fishery advances. A sustained stream of high quality meals and oils will be provided to the domestic aquaculture feed manufacturers to insure contaminant and disease free food based on cold water marine resources.

Anonymous one

By 2013, a new fishery will open for urchins as a natural marine source of color in the flesh of aquacultured fish. This, combined with the natural color in salmon meal and oil, will provide a more robust color to many of the aquacultured fish. Grants will be in place for research to find effective ways to: harvest isopods and amphipods allowing for a new source of aquaculture food while improving the quality of fish caught with pots and longlines; support the handling of sport charter caught fish processing waste and enable transport of the daily catch waste to be added to a stabilized waste stream; harvest Arrowtooth Flounder for reduction;
develop appropriate food blends that maximize the use of marine and terrestrial plant and animal proteins, oils, and nutrients.

By 2033, Alaska will have full recovery of the commercial and sport fishery waste, as well as managing the aggressive marine invertebrates, thus improving the ecosystem. Alaska will venture away from export of meals and oils to domestic aquaculture to enhanced ecosystems with open-ocean ranching and specialized foods in a sustained large marine ecosystem approach. Alaska's continental shelf will be maintained in a balanced ecosystem with sustained productivity of preferred species. Specialized ships will distribute feed to lure preferred species into concentration at known locations for very efficient harvest (high cpue). Regional enhancement facilities will be growing fish, including halibut, sablefish, and pacific cod, to a post larval stage for return to the "open ocean ranch". Offshore fisheries will show comparable growth rates and production to that seen in the history of the Alaska salmon enhancement programs. A plateau will be reached with sustained TAC of 4.5 Million MT and a TAC on halibut, cod, and sablefish that is 3 times the 2007 harvest level.

In summary, the return of the natural fish and marine invertebrate proteins and oils to the ecosystem, along with an enhancement program for the preferred ocean fish of our region will lead to an enhanced ecosystem that optimizes the annual production of the large marine ecosystems of Alaska's continental shelf. However, to get there, Alaska will need to optimize the use of its marine resources by maximizing the recovery of seafood processing waste and conducting reduction fisheries on unused biomass, including Arrowtooth Flounder and the aggressive natural marine predators of urchins (herbivore on kelp habitat) and isopods and amphipods (captured fish). These materials will need to be used to nurture fish and establish growth rates on the important indigenous species, as well as develop feeding/aggregating behavior schemes, so that open ocean ranching through ecosystem enhancement can be managed and the species effectively harvested. A national aquaculture program can provide just such a research and development tool to answer these questions in a controlled but commercially viable environment.

Anonymous Two

Five years out

Work still being done to replace or decrease the use of fish meal and fish oil in aquafeeds.

A more efficient and cost effective way to clean fish oils of contaminants will be developed so more oil is available for feeds and human consumption.

Microarray analyses will have been used to determine the effect of new ingredients on the fish at a genetic level. This information will help guide the choices of ingredients to use in fish feeds. EPA will have a greater role in deciding how much of the nation's crops are converted to biofuels and how quickly this happens. EPA's decisions will affect the price of commodities including corn and soybeans.

Twenty-five years out

Ocean waters continue to see a drop in pH. The changing environment in the oceans will have a major impact on the food chains and productivity negatively impacting the remaining fish stocks; this includes both food fish and fish meal stocks.

Strains of fish have been selected for that can tolerate and thrive on high levels of soybean meal and other vegetable proteins in their diet. With the evolution of biofuels an "if then" scenario will occur. If the biofuels industry continues to grow then the byproducts of biofuel manufacture will be used in feeds. If biofuel development does not grow as much as expected then more grains will be available for feeds. Basically it is unknown how biofuels will impact the availability of feedstuffs.

Anonymous three

Anonymous Three

Species known–salmonids, especially Atlantic salmon diets must include animal protein sources because salmonids are carnivores so need the sum of all of animal matter (amino acids, nucleotides, organic acids, taurine, methyl amines etc). Plant protein concentrates are expensive and must include too many micro-nutrients to be a viable replacement of fish meal. However, plant protein concentrates are extensively used and are important. Growth rates are influenced at least equally by farm management/environment and feed so feed can be made with cheap materials ie. fish meal can be replaced.
FCR is critical and a good index to evaluate plant + animal protein mixes.

Many potential sources exist but economic sources are very rare and limited. Less necessary than "breakthroughs" is competition amongst animal feed protein suppliers to produce high quality and low priced feedstuffs. The industry is relatively small and will benefit most from new suppliers rather than new ingredients. This may mean that large food suppliers will be attracted to the aquafeed industry. In particular protein concentrates of 60+ percent are limited in supply.

Breakthroughs will be in better understanding of the negative nutrients. We know well the essential nutrients but each new product tested seems to not perform as predicted by amino acid composition due to "anti-nutrients". A public funded consortium in this area is critical.

The most limiting nutrient for salmonids will certainly be omega 3. The IFFO and FAO have projected that fishoil demand (the only current economic source of omega 3) already exceeds supply and prices are rising rapidly. In addition the human food industry is adding omega 3 to milk, yogurt etc and driving demand and prices up even more. The solution is micro-organism cultures and companies exist. That this product becomes economical so that consumers eat oil rich fish for health versus cheap chicken is a great challenge, perhaps requiring special targeted funding.

Protein sources can and should come from waste or co-products or by-products. In particular poultry meal made from chicken processing waste is an excellent alternative to fish meal and sustainable.

Thus, sustainability is much more dependent on fish oil replacement for which there are no alternatives today.

In addition, El Nino years cause a 30+ percent drop in fish meal and oil and the next one (?2010) will be an economic disaster for the aquafeed industry.

Anonymous Four

Aquafeeds–2013

Biofuel byproducts/coproducts (primarily DDGS) continue to grow in quantity. By 2013, it is predicted that many ethanol manufacturing plants will implement very aggressive quality control programs, which will substantially reduce variability (e.g., in moisture content, total protein, amino acid profiles, etc.) for individual plants over time. Still, however, there are drastic differences between processing plants. Thus, use of these coproducts in aquafeeds will be dependent upon selecting DDGS from a specific processing plant that will appropriately meet the nutrient requirements for specific end-users.

Storage and handling (flowability issues) will be resolved, which makes their use much more favorable, regardless of location without, or even outside, the country (i.e., transportation and logistics is no longer an issue).

The quantity of DDGS produced will have grown to such an extent that DDGS has become a much lower-cost feed ingredient versus other vegetable-based materials. As such, use of DDGS will completely replace other corn-based materials which have historically been used in aquafeeds. The impetus for this change has been driven by the fact that more corn will be used for conversion to fuel ethanol vis-à-vis other end uses. At this point in time, there is not only great interest in using DDGS as an aquaculture feed ingredient, primarily as a supplementation versus a complete protein source, but many commercial feeding operations will have proven their effectiveness.

Many feeding trials will be conducted by 2013, in a variety of species. Promising results will be seen with inclusion levels of unmodified DDGS of up to 30 percent. High-protein (i.e., fractionated) DDGS can be effectively used up to 40 percent inclusion. A key to these high levels is the balancing act between providing appropriate nutrients (provided by the complete rations) versus optimizing processing techniques and conditions, in order to produce floating, pelleted feeds that do not have any binding problems.

Aquafeeds–2033

At this point in time, world oil production is in drastic decline, and the push for alternative fuels continues to escalate. World population growth, and its attendant repercussions, has nearly reached the earth's carrying capacity. The demand for food outstrips supplies, and aquaculture is increasingly relied upon to meet these needs.

Use of DDGS (both traditional/unmodified, as well as fractionated high-protein) are well established in aquafeeds by 2033. The biofuels industry has grown beyond the use of corn grain alone, however.

Individual futurecasts

Anonymous four

Biodiesel and lignocellulosic conversion processes have become economical and large scale. Unfortunately, many of the traditional feed ingredients are no longer available (for either livestock or aquafeeds), because they can be readily converted into biofuel as well.

Byproducts from these novel biofuel processes have grown substantially, and researchers must find ways to replace traditional feed materials. Preliminary feeding trials have shown that they have nutritional benefits for aquafeeds. Substantial research still needs to be conducted to determine which byproducts are appropriate for which species, and what inclusion rates are optimal for each.